

Deducing Air-Sea Fluxes from CBLAST Dropwindsonde Data

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LONG-TERM GOALS

Our ultimate objective is to understand and be able to predict changes in the intensities of hurricanes and to understand and be able to predict surface fluxes of enthalpy and momentum and hurricane wind speeds.

OBJECTIVES

The objective of the work carried out under this grant is deduce surface fluxes in the inner cores of Hurricanes Fabian and Isabel of 2003 from high resolution, GPS dropsonde data collected during the field phase of ONR's CBLAST experiment.

APPROACH

Our approach is to use atmospheric measurements collected in actual hurricanes to deduce surface fluxes of enthalpy and momentum. These measurements consist of wind, temperature and humidity measured directly from research reconnaissance aircraft and from GPS dropwindsondes deployed from those aircraft. Such measurements are first used to construct the azimuthally averaged radius-height distributions of angular momentum, total energy and radial velocity. Then, assuming that the storm is in an approximately steady state, the radial advections of moist static energy and angular momentum are calculated, and the surface fluxes of angular momentum and enthalpy are deduced as those needed to maintain a steady state. This approach has been taken (for angular momentum only) by Hawkins and Rubsam (1968), but they had to rely on measurements somewhat inferior to those available today. This work is being carried out under the leadership of the principal investigator Kerry Emanuel of MIT, working in collaboration with Michael Montgomery of the Naval Postgraduate School in Monterey and Michael Bell, a graduate student at Colorado State University in Fort Collins.

WORK COMPLETED

During the CBLAST field campaign of 2003, we were greatly successful in obtaining high-quality, GPS dropwindsondes in high-density arrays across the eyewalls of 2 intense hurricanes: Fabian and Isabel. These sondes were processed during the remainder of 2003 and 2004 by Michael Black of NOAA/HRD in conjunction with the PI during visits by the PI to HRD. We expected to complete the analysis by the end of 2004, but found that the deduced fluxes were overly sensitive to assumptions about the exact location of the storm center as well as to the exact subset of sondes used in each radial

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pass. This led us to a comprehensive analysis of the error sources in deducing surface fluxes as budget residuals.

During 2004-2005, initial estimates of surface fluxes were made by Jeanne Davencens, a French intern working with the PI. This work identified specific sources of error in estimating surface fluxes, having to do with storm centering and the assumption of steady conditions. In the view of the PI, the error bars associated with these initial estimates were unacceptably high. At about this time, the PI heard a talk by a CSU graduate student working with Michael Montgomery, in which the student, Michael Bell, had performed a detailed analysis of dropwindsondes collected during Hurricane Isabel, using a Barnes Analysis technique. We decided to take a much more detailed and comprehensive approach to the analysis of CBLAST dropsonde data. The first step in the process was to sample the output of highly detailed numerical simulations of hurricanes – in which the surface fluxes are known – using a sampling technique similar to dropwindsondes, and to introduce realistic errors in the storm center position and in the dropsonde data themselves in order to understand how well we can do in principle.

Work on sampling numerical output was begun in late 2005 and is ongoing. Much of this work is being carried out by Michael Bell under the supervision of the PI. We have now quantified much of the source of error in the budget technique for deducing surface fluxes and are preparing to turn back to the CBLAST dropsonde data in late 2007 to complete the analysis.

RESULTS

The budget technique consists of integrating the conservation relation for energy and angular momentum over a control volume that spans regions of very high surface wind speed. The angular momentum balance can be written

$$\int_{bot}^{top} F_{outer}^M dz - \int_{bot}^{top} F_{inner}^M dz + \int_{inner}^{outer} F_{top}^M r dr - \int_{inner}^{outer} F_{bot}^M r dr = \iint \frac{\partial \rho M'}{\partial t} \square 0, \quad (1)$$

where F is the net (mean plus turbulent) flux of angular momentum, and *inner*, *outer*, *bot*, and *top* refer to the four sides of a rectangular control volume, illustrated in Figure 1 below:

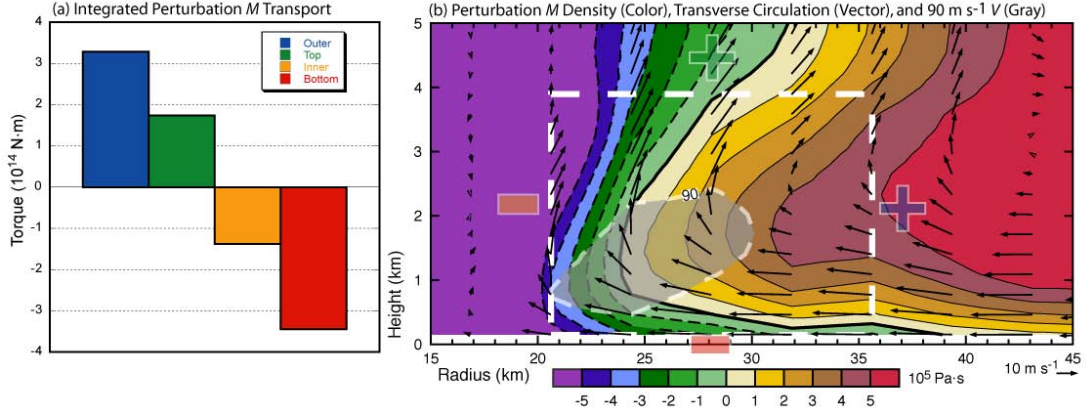


Figure 1: Angular momentum budget results from an integration of the axisymmetric, nonhydrostatic numerical model of Rotunno and Emanuel (Rotunno and Emanuel, 1987). The budget is integrated over a control volume given by the white, dashed rectangle in the right panel; the inner gray area denotes net winds speeds greater than 90 m s^{-1} . The perturbation angular momentum density is shown by the colored shading, and the mean wind in the radial-vertical plane is given by the black arrows. At left is the flux of angular momentum across each of the four sides of the control volume.

In deducing the flux of angular momentum across the bottom of the control volume from that measured across the other three sides, we assume that the tendency term in (1) vanishes. We can then compare the deduced flux to the actual flux in the model. We have done this for the axisymmetric, nonhydrostatic model of Rotunno and Emanuel (1987) and also for an integration of the MM5 three-dimensional mesoscale model. In the latter case, we average the properties of the simulated vortex in azimuth and then perform the budget analysis.

Exactly the same kind of analysis can be done for the total energy, defined

$$E \equiv c_p T + L_v q + gz + \frac{1}{2} |\mathbf{V}|^2, \quad (2)$$

where c_p is the heat capacity at constant pressure, T is the temperature, L_v the latent heat of vaporization, q the specific humidity, and \mathbf{V} is the three-dimensional velocity vector. The energy budget is then

$$\int_{bot}^{top} F_{outer}^E dz - \int_{bot}^{top} F_{inner}^E dz + \int_{inner}^{outer} F_{top}^E r dr - \int_{inner}^{outer} F_{bot}^E r dr = \iint \frac{\partial \rho E'}{\partial t} \square 0. \quad (3)$$

An example of the energy budget calculated from the Rotunno and Emanuel (1987) model is shown in Figure 2; this can be used to deduce the surface enthalpy flux and thereby the enthalpy exchange coefficient. As with angular momentum, we have done this with both the Rotunno and Emanuel 1987 model and an integration of the MM5 mesoscale model.

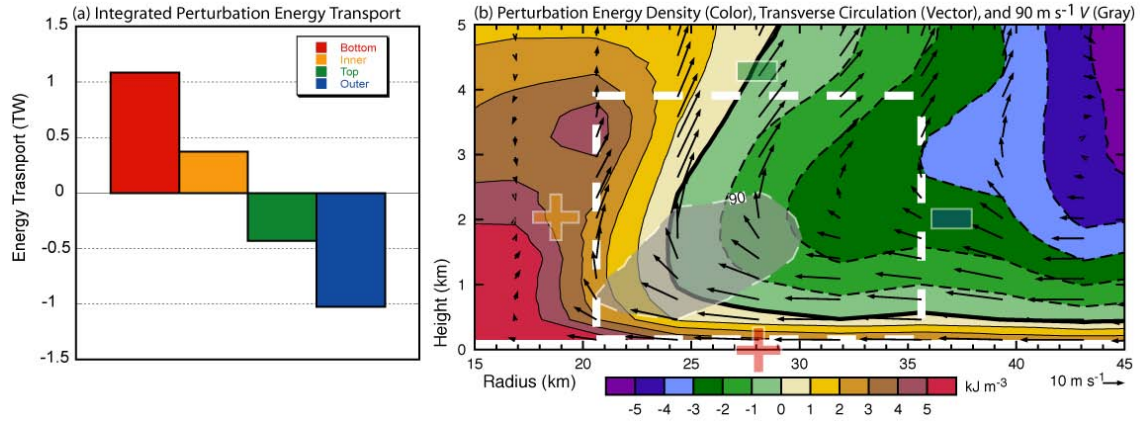


Figure 2: Total energy budget results from an integration of the axisymmetric, nonhydrostatic numerical model of Rotunno and Emanuel (Rotunno and Emanuel, 1987). The budget is integrated over a control volume given by the white, dashed rectangle in the right panel; the inner gray area denotes net wind speeds greater than 90 m s^{-1} . The perturbation energy density is shown by the colored shading, and the mean wind in the radial-vertical plane is given by the black arrows. At left is the flux of energy density across each of the four sides of the control volume.

Accounting for the neglect of the time-dependent terms and errors likely to be made in estimating the position of the storm center, we have estimated the surface exchange coefficients in both models and compared them to the known values of those coefficients, as shown in Figure 3. The error bars are unacceptably large in the Rotunno and Emanuel simulation cases. This turn out to be because large, axisymmetric inertial oscillations are present in that simulation, spoiling the assumption of quasi-steady flow. The error bars for the three-dimensional MM5 simulation are reasonably small, however, in part because those simulations do not contain large quasi-inertial oscillations.

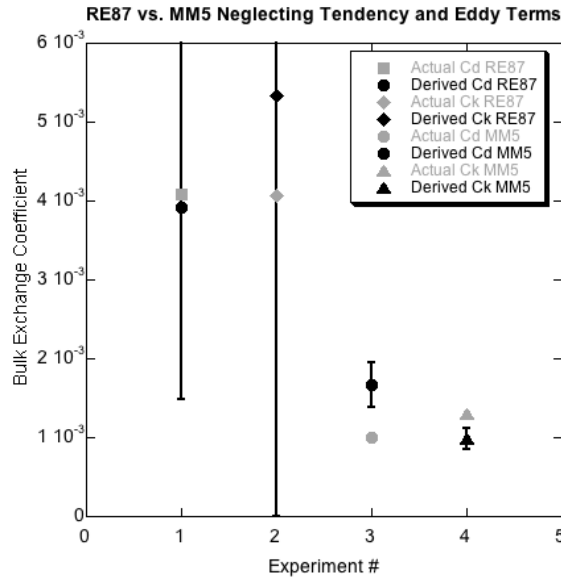


Figure 3: Estimated (gray) and derived (black) surface exchange coefficients, with error estimates. From left to right: drag coefficient and enthalpy exchange coefficient from the axisymmetric model, drag coefficient and enthalpy exchange coefficient from a simulation using the MM5 model.

These results have taught us how to go about analyzing the actual dropwindsonde data collected during CBLAST and to estimate errors in our estimates of the surface exchange coefficients.

IMPACT/APPLICATIONS

While it is too soon to predict how the results obtained thus far will influence science, it is safe to say that any better estimates of the behavior of air-sea exchange at hurricane wind speeds will further efforts to improve hurricane intensity prediction.

TRANSITIONS

Meaningful transitions must await analysis of the field experimental data.

RELATED PROJECTS

None at the moment.

SUMMARY

We have collected aircraft measurements of wind, temperature and humidity in two CBLAST hurricanes and will use them to deduce the drag that hurricane winds exert on the ocean surface, and the evaporation of seawater into a hurricane, which is the process that fuels the storm. Understanding the drag and the evaporation is crucial for understanding and predicting changes in hurricane wind speeds. We have applied our technique to the analysis of numerically simulated hurricanes in order to understand sources of error and the overall validity of the technique. These results are encouraging and have taught us how to approach analysis of the actual data, which we will undertake this academic year.

REFERENCES

Hawkins, H. F. and D. T. Rubsam, 1968: Hurricane Hilda, 1964: II. Structure and budgets of the hurricane on October 1, 1964. *Mon. Wea. Rev.*, **96**, 617-636

Rotunno, R. and K. A. Emanuel, 1987: An air-sea interaction theory for tropical cyclones. Part II. *J. Atmos. Sci.*, **44**, 542-561

PUBLICATIONS

None so far.

PATENTS

None.

HONORS/AWARDS/PRIZES

None.